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Effect of harvest cycle on logistics, working time requirement and costs of harvest of short rotation forestry

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Abstract

When harvesting short rotation forestry (harvest cycle 2-4 years) with a forage harvester equipped with a specifically designed header the working time requirement and the operating costs are lowest per ton of dry matter. On the other hand, due to the high water content of about 55 % the chips are not storable without artificial drying. Furthermore they cannot be used in small biomass furnaces (<150 kW) because of their particle size. When the feller-bundler is used for plants with a harvest cycle of 5 to 10 years on plots smaller than 1 ha, similar mass flows are achievable. However, the transport of the trees for storing it at the interim storage at the edge of the field leads to higher working time requirements and costs. In addition, the trees have to be chopped after storing. This leads to significantly higher costs for plots with a larger size. In comparison with the method of the forage harvester the costs have more than tripled. On small plots the difference decreases to 30 % (about 150 €/t dry matter). However when harvesting with the feller-bundler the water content of the wood chips can be reduced to below 35 % because of the interim storage of the trees at the edge of the field from winter till end of the summer. Furthermore, it is possible to vary the particle size of the chips depending on the setting of the chipper. Therefore, the prices can be varied in a more flexible way and the higher production costs on smaller plots can be offset. Agricultural enterprises harvesting wood semi-manually with a chainsaw for self-sufficiency should do so only in case of a harvest cycle of 5 to 10 years and with trees having larger trunk diameters.

Keywords: short rotation forestry, harvest cycle, logistics, operation costs

1 Introduction

In Austria, short rotation forestry is rarely seen on larger plots especially when major power plants should be supplied with wood chips for heating reasons. Farmers planting short rotation forestry prefer to provide smaller biomass heating plants or their own enterprise with wood chips from fast-growing plants like poplars or willows. In this case mainly smaller plots are used that are often difficult to cultivate with larger agricultural machines and equipment. In this context, the question of optimal planting density and harvest cycle arises. Both have an influence on the applicable harvestings methods and therefore also on the required working time, costs and quality of the wood chips.

2 Materials and methods

The analyses were made between 2009 and 2013 on areas cultivating poplars. When using a harvest cycle of 2 - 4 years the poplars were planted in rows with a distance of 200 – 300 cm. Within the row, the distance was between 50 and 60 cm. In case of a harvest cycle of 5 - 10 years, the distance between the rows was 250 to 300 cm and the distance within the row grew to 300 cm. The tests were made with the first two harvests.

For data collection all operations were divided into parts of an operation and work elements (*Handler and Blumauer 2013*). For collecting labor input of the individual work elements, the digital time measurement system Ortim a3 was used. Distances were measured by means of GPS. The diameter of the trunk D10 was determined by a caliper. The mass of harvested wood was derived from the traction force using a measuring system on the front-loader. The mass of harvested wood chips was determined by using a weighbridge. For determining the quality of the wood chips the particle size according to CEN/TS 15149-1 and EN 15149-1, the bulk density of the wood chips in accordance to CEN/TS 15103 and EN 15103 and the dry matter content according to CEN/TS 14774-2 and EN 1744-2 were identified. Samples were taken according to CEN/TS 14778-1 and EN 14778. Statistical evaluations of the work-studies were done by ORTIMzeit Professional and SPSS 19.0. Model calculations were done based on determined times relating to the complete working process from field to storage.

The calculated operating costs include the fixed and the variable costs of the machines as well as the wages of the workforce. Data for labor and machinery costs were obtained from agricultural contractors and machinery cooperatives.

Two logistic chains were analyzed for plantations with a harvest cycle of 2 - 4 years:

- Procedure 1: The wood was harvested with a forage harvester equipped with a special header. The theoretical cutting length was adjusted to 34 mm. Due to the working width of 1.2 m the header was able



Figure 1: Forage harvester equipped with a special header

to cut down one row of poplars. The distance between the rows was 3 m. The header was able to cut trunks with a diameter up to 13 cm. The harvester blew the wood chips into tractor-pulled trailers driving on the side that transported them to the storage.

- Procedure 2: In case of the semi-manual harvesting the trees were cut with a chainsaw. The wood was immediately bundled by a second worker and loaded on a trailer by a crane. Then it was transported to a storage place at the field edge and piled up. After drying during the summer the trees were chopped by a chipper. Finally, tractor-pulled trailers transported the chips to the final storage.



Figure 2: Felling, bundling and transporting the trees at semi-manual harvesting (Procedure 2)

Analyzed logistic chains for plantations with a harvest cycle of 5 - 10 years:

- Procedure 3: In this case, the trees were felled with a chain-saw; an accompanying worker pressed the felled tree into one direction with the help of fork. The felled trees were bundled by a forest tractor equipped with a crane. Another tractor equipped with a log grapple and a front-end loader pushed the wood aside to a storage place. There the trees were piled up. After drying the trees were chopped by a chipper and then chips were transported to the final storage with tractor-pulled trailers.



Figure 3: Felling and bundling the trees at semi-manual harvesting (Procedure 3)

- Procedure 4: A feller-bundler piled the felled trees up. A tractor equipped with a log grapple transported the bundles to the storage place at the edge of the field. Afterwards the trees were piled up by a front-end loader. After drying the trees were chipped and the chips were transported to the final storage with tractor-pulled trailers.



Figure 4: Harvesting with a feller-bundler (Procedure 4)

3 Results and discussion

The detailed results of the time studies have been published in *Handler and Blumauer 2013*. The following values are basing on these data.

The model calculations are including the working time requirement and the operating costs for felling the trees up to transporting the wood chips over a distance of 1 km.

3.1 Model calculations for a harvest cycle of 2 - 4 years

3.1.1 Direct-chip harvesting with a forage harvester

In case of Procedure 1 the working time requirement for the forage harvester relating to dry matter depends essentially on the plot size (see Figure 5). With increasing plot size the working time requirement for turning at the headland, set-up times when arriving and leaving as well as changing the plots significantly decreases. Therefore planting short rotation plantations on small plots leads to a significant increase of working time requirement. This is particularly important when plantation is planted on small plots.

The operation speed of the harvester is limited due to the destruction of stools. Therefore, lower yields lead to a considerable decrease of mass flow and increase the required working time (see Figure 5). When achieving a level that is not influenced by the driving speed but by the power of the harvester the working time requirement (related to mass flow) cannot be reduced anymore by higher yields.

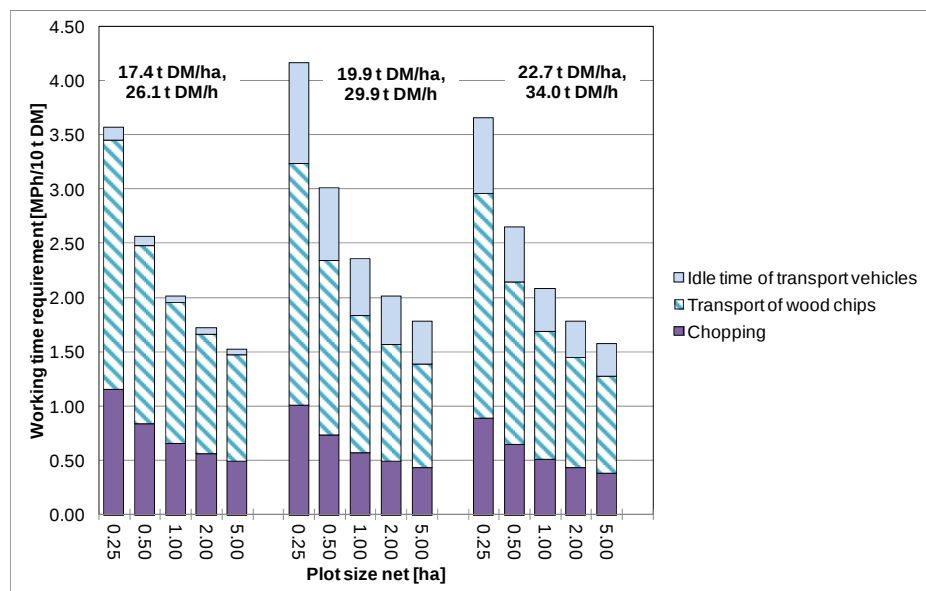


Figure 5: Working time requirement¹ for direct-chip harvesting depending on net plot size, yield and mass flow

The time required for transporting the wood chips depends proportionally on the time required for the harvester and decreases with a larger plot size. A further increase of the mass flow from 26.1 to 29.9 tons DM/h leads to a lower filling time per transport vehicle. Therefore, an additional transport vehicle will be necessary to avoid idle times for the forage harvester. When

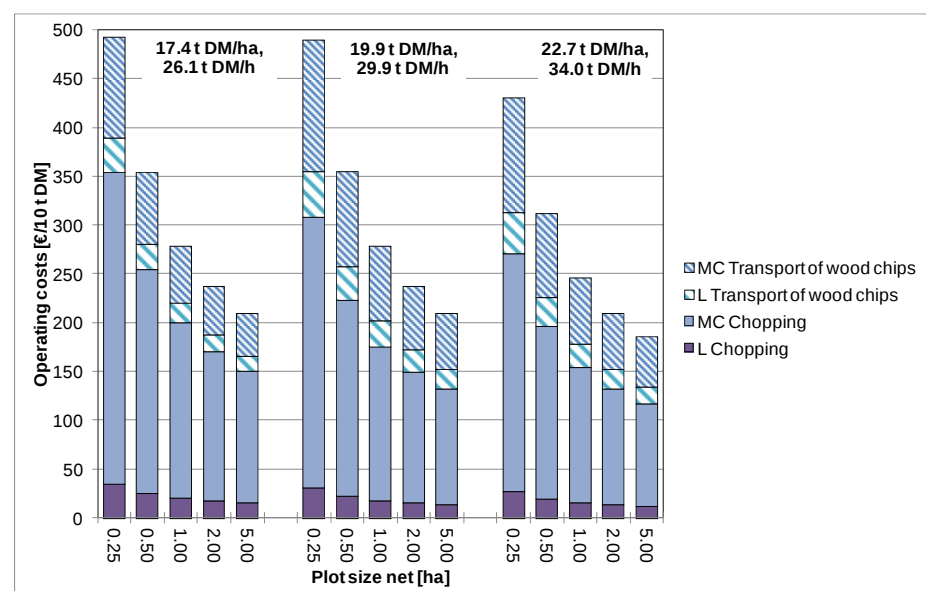


Figure 6: Operating costs for direct-chip harvesting depending on plot size, yield and mass flow through the forage harvester)²

three transport vehicles are necessary the required working time for transport increases significantly. The further increase of the mass flow from 29.9 to 34.0 tons DM/h improves the degree of capacity utilization for the transport vehicles. Idle times of the transport vehicles can be reduced. A higher mass flow reduces the required working time again until a fourth

¹ DM...dry matter, MPH...man power hour

Row distance 3.0 m and distance within the row 0.5 m

Plot size net (ha) = total row length (m) x average row distance (m) / 10000. The possible utilization of the whole area for producing energy wood depends on the turning zone (headland) and the prescribed distance to the neighbouring areas.

Mass flow relating to pure time for chopping (without time for turning at the headland and other sub-processes)

² Working time requirement see Figure 5, labor costs chopping 30 €/h, labor costs transport 15 €/h, machine costs forage harvester (370 kW) 290 €/h, machine costs transport vehicles (tractor with push-off trailer 25 m³) 47 €/h, L...labor costs, MC...machine costs

transport vehicle will be necessary. The operation costs in Figure 6 base on the working time requirement in Figure 5. They are mainly influenced by the costs for the machinery having a proportion of more than 80 %.

The wood chips produced by the forage harvester have a lower dry matter content of approximately 45 % and have to be dried before storage. Beside that the chips are not suitable for smaller furnaces (<150 kW) due to particle size distribution. For this reason farmers are still searching for alternative techniques of harvesting which are able to produce chips that are suitable for storage and can be used for small furnaces. The results presented below show three methods meeting these requirements.

3.1.2 Semi-manual harvesting

In case of Procedure 2 the procedure of felling and bundling the trees carried out by two workers takes more than 80 % of the whole working time. The higher yield at the same plant distance (2.0 x 0.5 m) leads to increasing average masses of trees. Therefore, the working time requirement for felling and bundling can be reduced (see Figure 7, variation yield). The same result can be

seen when the number of stools per hectare is reduced by larger plant distances. This leads to a higher yield per stool; the total yield remains constant (see variation plantation design).

The mass per bundle does not affect the required working time for felling and bundling in the analyzed studies (see variation mass of bundle). On the other hand, the mass of bundles and the size of the trailer have influence on the transport of the trees to the edge of field (see variation mass of bundle and capacity of trailer). The increasing bundle mass reduces the working time requirement for loading and unloading the trailer with an adapted crane clamp. Using a larger trailer reduces the driving times. If the trees are directly chipped at the pile at the edge of field after drying, the required working time for chipping and transporting the chips decreases with higher yield due to the lower set-up times per mass. This effect mainly occurs in case of plot sizes below one hectare. In general, the set-up times per mass for powerful chippers increase on plots below one hectare if the harvested trees of each plot are separately stored at the edge of the field.

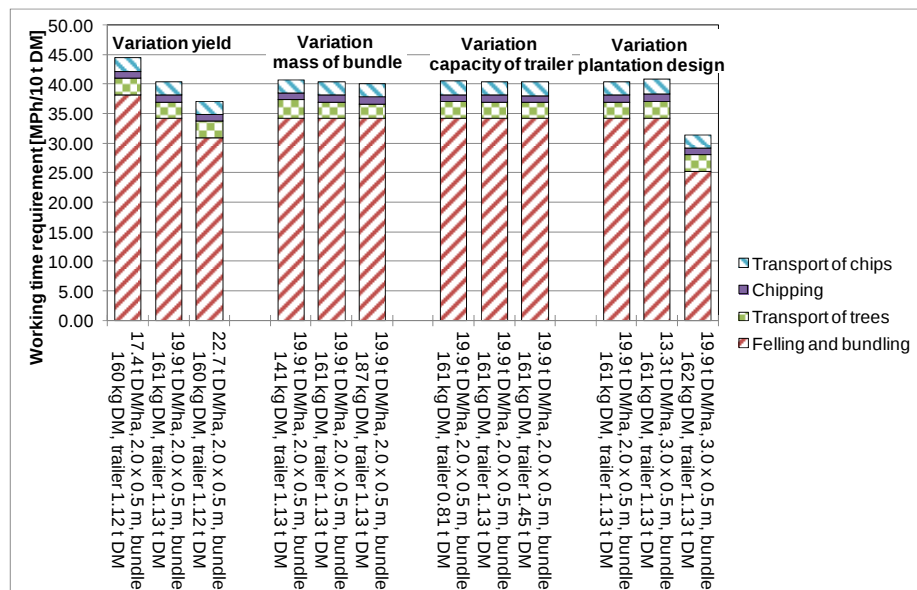


Figure 7: Working time requirement for semi-manual harvesting (harvest cycle 2 - 4 years)

For example the working time requirement and the costs for chipping rise by 25 % when the plot size decreases from 0.50 ha to 0.25 ha. This procedure is not applied on plots larger than 1 ha because the required working time would be too high.

The operating costs for felling and bundling have a share of 46 up to 56 % and therefore play the most important role (see Figure 8). The procedure of chipping the trees causes 21 to 25 % of the operating costs because of the high costs for the chipper.

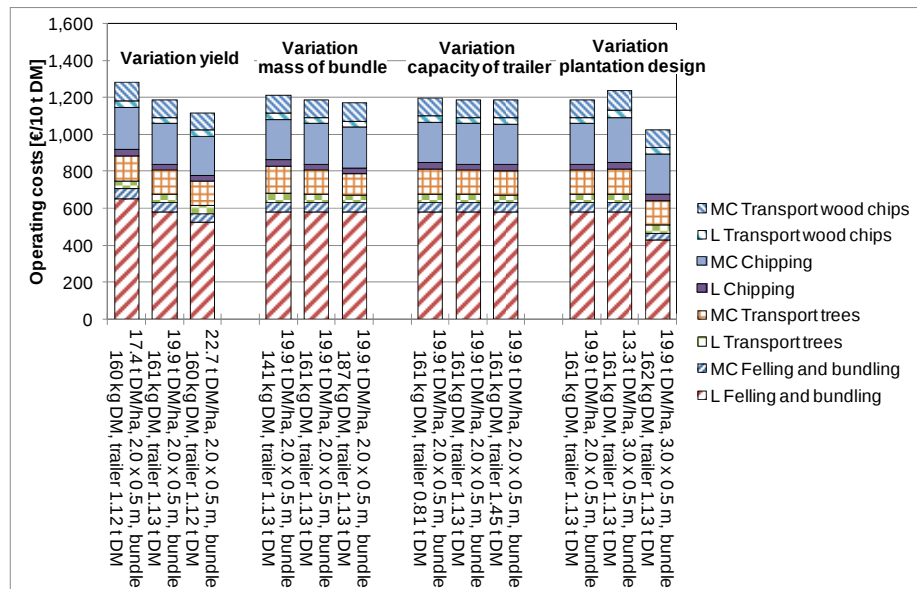


Figure 8: Operating costs for semi-manual harvesting (harvest cycle 2 - 4 years)³

3.2 Model calculations for a harvest cycle of 5 - 10 years

3.2.1 Semi-manual harvesting

In case of Procedure 3 felling of the trees takes 40 to 46 % of the working time requirement and plays therefore the most important role. The higher yield at the same plantation design leads to increasing average masses of trees. Therefore, the working time requirement for felling and bundling can be reduced (see Figure 9, variation yield). The same result can be

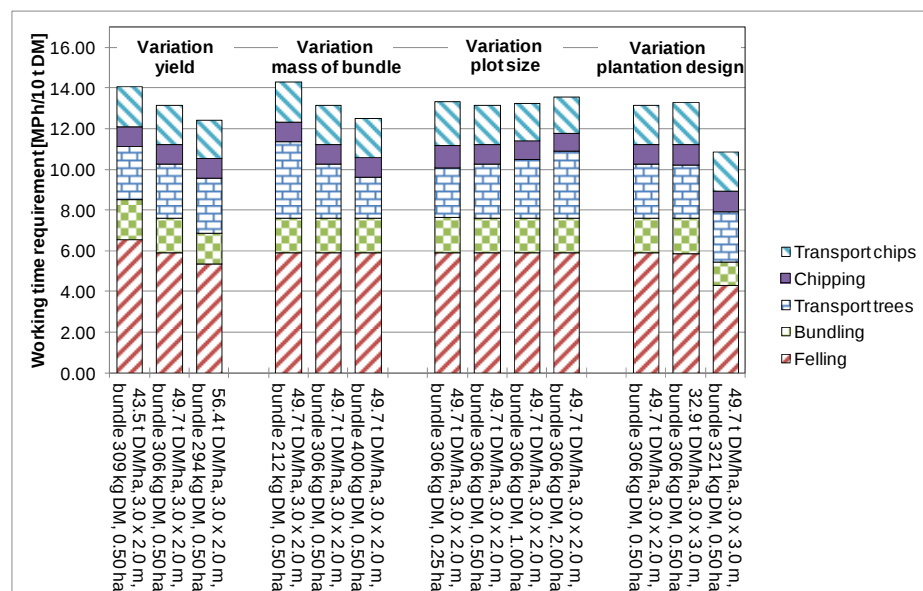


Figure 9: Working time requirement for semi-manual harvesting (harvest cycle 5 - 10 years)

seen when the number of stools per hectare is reduced by larger plant distances. This leads to a higher yield per stool; the total yield remains constant (see variation plantation design).

³ Working time requirement see Figure 7, labor costs felling and bundling 17 €/h, labor costs chipping 30 €/h, labor costs transport 15 €/h, machine costs chainsaw 4 €/h, machine costs transport of trees (tractor with trailer and crane) 49 €/h, machine costs chipper (95 m³/h) 212 €/h, machine costs transport vehicles (tractor with push-off trailer 25 m³) 47 €/h

The mass per bundle does not affect the required working time for felling and bundling in the analyzed range (see variation mass of bundle). On the other hand, the mass of bundles has a significant influence on the transport of the trees to the edge of field. The increasing bundle mass reduces the working time requirement for loading and unloading the bundles. The in-

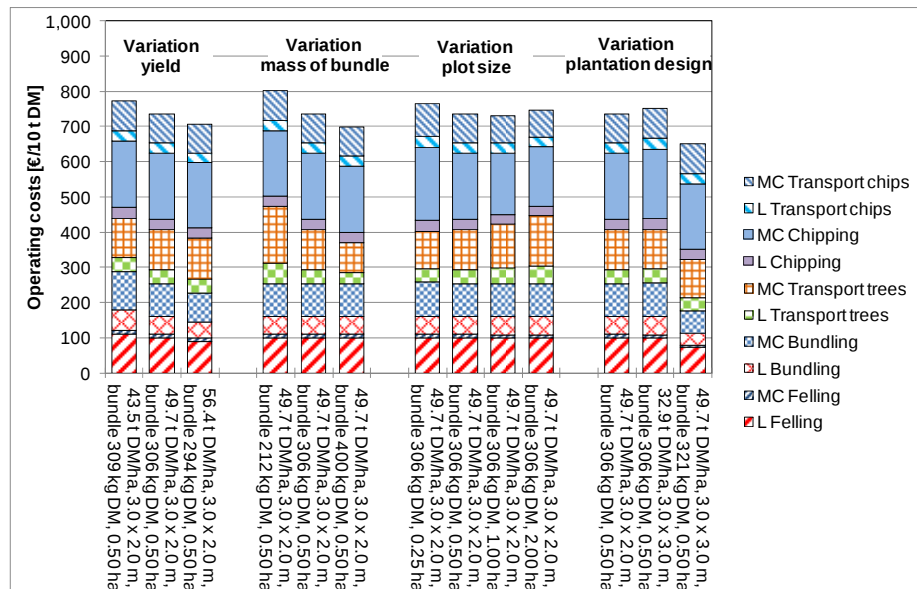


Figure 10: Operating costs for semi-manual harvesting (harvest cycle 5 - 10 years)⁴

creasing mass also reduces the driving times related to the transported mass. However, this can only be achieved if the bundle exactly fits into the log grapple and is therefore optimally aligned. If the trees are directly chipped at the field after drying, the required working time for chipping and transporting the chips declines slightly with higher yield due to the lower set-up times per mass. This effect mainly occurs in case of plot sizes below half a hectare. For example the working time requirement and the costs related to the chipped wood increase by 11 % when the plot size decreases from 0.50 ha to 0.25 ha.

In case of plot sizes larger than one hectare the working time requirement for transporting the trees to the piles increases much more relating to the decrease of working time requirement for chipping (see variation plot size) due to the longer transport distances within one plot. In this case a second pile should be set up.

For this procedure, the operating costs for bundling and transporting the trees as well as the chipping process are most significant (see Figure 10).

3.2.2 Harvesting with a feller-bundler

When harvesting with a feller-bundler the process of felling the trees is highly mechanized. Moreover, it is possible to combine this working process with the process of bundling (see Procedure 4). Therefore, the working time requirement can be reduced by more than 80 % with regard to felling and bundling separately as described in Procedure 3. Furthermore the operating costs can be reduced by about 50 %.

⁴ Working time requirement see Figure 9, labor costs felling 17 €/h, labor costs bundling and chipping 30 €/h, labor costs transport of bundles and chips 15 €/h, machine costs chainsaw 4 €/h, machine costs bundles (forest tractor with crane) 55 €/h, machine costs transport of trees (tractor with log grapple and front-end loader) 45 €/h, machine costs chipper (95 m³/h) 212 €/h, machine costs transport vehicles (tractor with push-off trailer 25 m³) 47 €/h

The higher yield at the same plant distance leads to increasing average masses of trees. Therefore when using the feller-bundler the required working time for felling and bundling can be lowered (see Figure 11, variation yield). The same result is achievable when the plant distance within the row is increased. The total yield remains constant (see variation plantation design). The working time requirement for felling and bundling is not affected by the bundle masses (see variation mass of bundle). The working processes of transporting the trees and chipping and transporting the chips are the same as in Procedure 3.

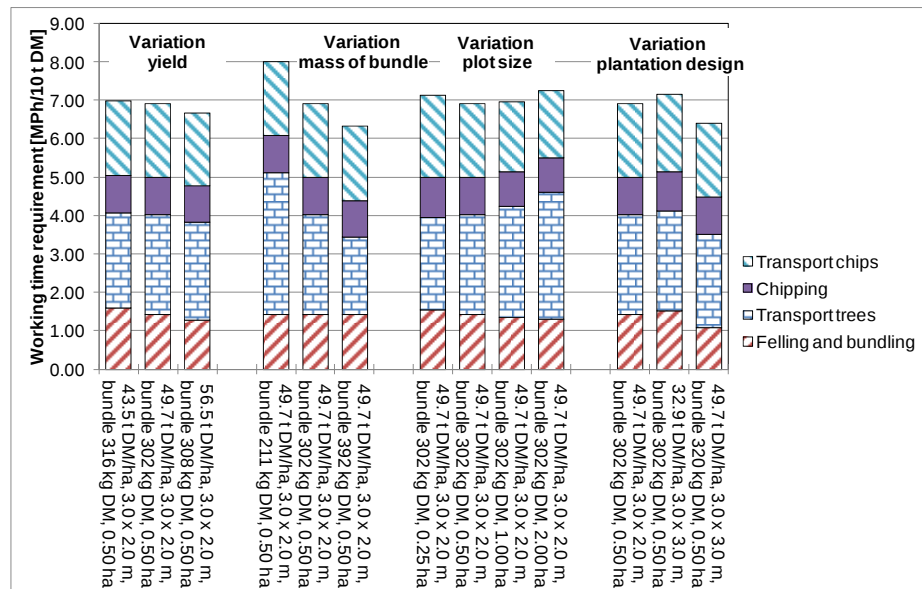


Figure 11: Working time requirement when harvesting with a feller-bundler

Along with the process of chipping, the transport of trees plays the most important role with regard to the operating costs (see Figure 12). If special forest tractors, which are able to transport two bundles at once, were used, the cost could be reduced.

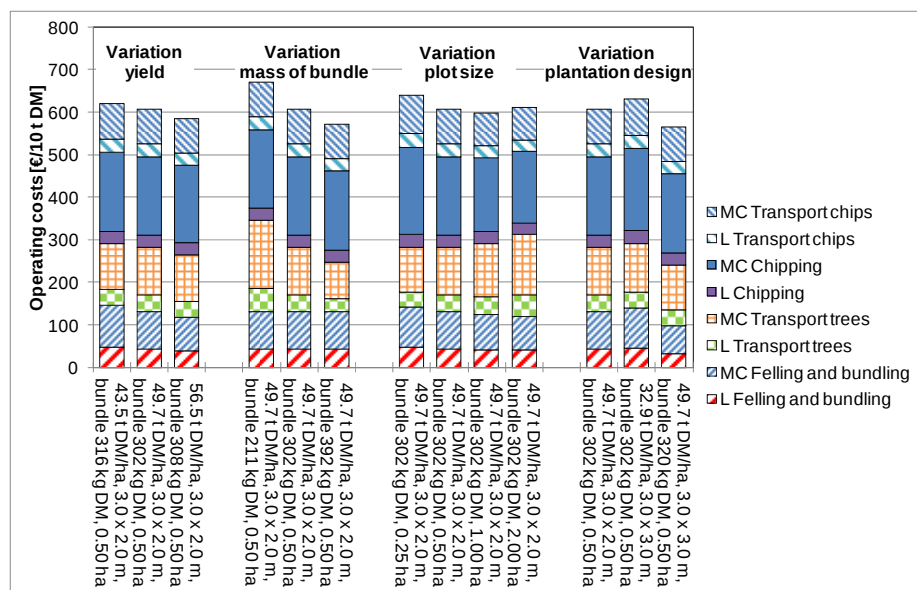


Figure 12: Operating costs when harvesting with a feller-bundler⁵

4 References:

Handler, F. und E. Blumauer (2013). Optimierung von Verfahren für die Bewirtschaftung von Kurzumtriebsflächen. Forschungsbericht, BLT Wieselburg, Ifz Francisco Josephinum, Austria.

⁵ Working time requirement see Figure 11, labor costs feller-bundler and chipping 30 €/h, labor costs transport of bundles and chips 15 €/h, machine costs feller-bundler 65 €/h, machine costs transport of trees (tractor with front-loader and log grapple) 45 €/h, machine costs chipper (95 m³/h) 212 €/h, machine costs transport vehicles (tractor with push-off trailer 25 m³) 47 €/h